

band with marker *Vp-1B3* associated with PHS resistance (Fig. 2, p. 68). These results give an indication of the resistance associated with these markers.

One interesting observation to come out of this study is that the combination of *DuPw004* and *Vp-1B3* markers associated with resistance showed a GI range of 0–0.25. However, the results will be confirmed when more resistant type genotypes are included. Three genotypes, lines 203 (FOW1) and 214 (CHIL/CHUM18//ARA90) from the 15th HRWYT and line 2070 (CHAPIO/FRET2) from the 18th HRWSN 2070, showed this combination.

References.

- Singh R, Matus-Cadiz M, Baga M, Hucl P, and Chibbar RN. 2010. Identification of genomic regions associated with seed dormancy in white-grained wheat. *Euphytica* DOI 10.1007/s10681-010-0137-8.
- Yang Y, Zhao XL, Xia LQ, Chen XM, Xia XC, Yu Z, He ZH, and Röder M. 2007. Development and validation of a viviparous-1 STS marker for pre-harvest sprouting tolerance in Chinese wheats. *Theor Appl Genet* 115:971-980.

JANTA VEDIC COLLEGE

Department of Genetics and Plant Breeding, Baraut Baghat (UP), India.

Gene action for quantitative traits in bread wheat.

Sarvan Kumar and Dharendra Singh.

Abstract. An experiment during rabi 2005–06 and 2006–07 estimated gene action in bread wheat. Seven wheat cultivars (DBW 14, HUW 468, HUW 533, GW 273, PBW 443, PBW 502, and DL788-2) were used for five straight crosses (DBW14/HUW468, DL788-2/PBW502, DBW14/HUW533, GW273/HUW468, and PBW443/HUW533) and six generations P_1 , P_2 , F_1 , F_2 , BC_1 , and BC_2 were obtained for each cross. A generation mean analysis was made on days-to-75% heading, days-to-maturity, plant height, effective tillers/plant, spike length, spikelets/spike, grains/spike, grain weight/spike, seeds/plant, 1,000-kernel weight, grain yield/plant, and at three different stages during *Helminthosporium* leaf blight infection (dough, soft dough, and hard dough). A majority most of the exhibited significant additive and dominance gene effects in scaling test on different characters in all the crosses indicating the presence of nonallelic interaction.

Joint scaling tests revealed that the simple additive-dominance model was adequate for spike length, grain weight/spike in all five crosses; for days-to-75% heading, days-to-maturity in cross PBW443/HUW533; for spikelets/spike in crosses DBW14/HUW468, DBW14/HUW533, and GW273/HUW468; and for 1,000-kernel weight and grain yield/plant in cross 'PBW443/HUW533'. For the remaining crosses, the model was not adequate. The six-parameter model was used for those crosses where simple additive-dominance model was inadequate. The classification of epistasis revealed the predominance of duplicate type of epistasis in a majority of the crosses for all the traits, whereas complementary type epistasis was present for seeds/plant in crosses 'DBW14/HUW468', 'DBW14/HUW533', and 'PBW443/HUW533'; days-to-maturity and effective tillers/plant in cross 'DBW14/HUW468'; spikelets/spike in cross 'DL788-2/PBW502'; and grains/spike and HLB-3 in cross 'DBW14/HUW533'. Based on the above findings, we concluded that attributes such as spike length and grain weight/spike are controlled by fixable genes and may be improved by adopting simple selection or any other breeding approach that can exploit additive effects. Attributes such as days-to-75% heading, days-to-maturity, plant height, tillers/plant, effective tillers/plant, and other related traits included in the study were controlled by both additive and nonadditive type of gene effects. Therefore, a breeding plan that can exploit both types of gene effects, such as intermating in early segregating generations followed by selection or reciprocal recurrent selection, might be useful. Heterosis breeding might be a useful tool for improvement of grain yield in wheat because it showed a complementary type of epistasis in most of the crosses in this study.

Introduction. Wheat is one of the main food crops of India and contributes significantly to the central pool. The cultivation of wheat in India started very early during prehistoric times and, thus, the origin of wheat is still a matter of speculation. Wheat research for development of high-yielding cultivars and improving management techniques started in India long ago. A large number of valuable cultivars were bred and released for commercial cultivation. These cultivars were tall and mainly suited to low-input management with low yield potential. However, a turning point in the history

of wheat breeding came during mid 1960s with the introduction of semidwarf, photinsensitive, high-yielding Mexican wheat breeding material developed at CIMMYT with the guidance of Nobel under the All India Coordinated Wheat Improvement Project. Three genotypes, Lerma Roja, S 308, and Sonara-64, that out yielded the old, tall wheat cultivars were released for general cultivation in major wheat-growing areas of India.

The improvement of quantitative traits through selection depends upon the nature and magnitude of the gene effect involved in the inheritance of that particular trait. Generation mean analysis, a first-degree statistic, is a simple but useful technique for characterizing gene effects for quantitative traits (Hayman 1958; Jinks and Jones 1958; Gamble 1962). Generation mean analysis estimates the epistatic effects. Both additive and nonadditive gene effects have been found to be important in wheat (Paroda and Joshi 1970; Singh and Singh 1992), however, both vary with the materials involved. The greatest merit of generation mean analysis lies in the estimate of epistatic gene effects, additive x additive (i), additive x dominance (j), and dominance x dominance (l), which is the most commonly used design. We have estimated the gene effects for yield and yield components using generation mean analysis.

Material and Methods. Seven diverse cultivars of bread wheat, DBW 14, HUW 468, HUW 533, GW 273, PBW 443, PBW 502, and DL788-2, were used in five cross combinations (DBW14/HUW468, DL788-2/PBW502, DBW14/HUW533, GW273/HUW468, and PBW443/HUW533), each with six basic generations P_1 , P_2 , F_1 , F_2 , BC_1 , and BC_2 . The material of five crosses was evaluated in a randomized block design with three replications in a plot size with 2.5-m rows spaced 23 cm apart with a plant-to-plant distance of 10 cm during rabi season 2006–07 at the Research Farm of Janta Vedic College, Baraut Baghpat. Data were recorded on ten randomly selected competitive plants from each replication of parental lines and 30 plants from each of the F_1 , F_2 , BC_1 , and BC_2 populations for 15 characters (days-to-75% heading, days-to-maturity, plant height, effective tillers/plant, spike length, spikelets/spike, grains/spike, grain weight/spike, seeds/plant, 1,000-kernel weight, grain yield/plant, and at three different stages during *Helminthosporium* leaf blight infection, i.e., HLB-1 (77–80 d, dough stage), HLB-2 (83–86 d, soft dough stage), and HLB-3 (87–89 d, hard dough stage). Mather's scaling test was used to identify the interacting crosses and a joint scaling test was used to test the adequacy of a simple additive dominance model (m, d, h; Mather 1949; Cavalla 1952). The genetic effects in the interacting crosses were estimated using a six-parameter model (m, d, h, i, j, l; Hayman 1958).

Results and Discussion. The mean performance for the different characters of each of the five crosses in different generations are given in Table 1 (pp. 71-72). The F_1 and F_2 populations were higher than the respective parents in cross 'DBW14/HUW468' for all the characters except days-to-maturity, 1,000-kernel weight, and all stages of HLB. Similarly, the high mean value of the F_1 and F_2 populations from their parents was observed in cross 'DL788-2/PBW502' for plant height, effective tillers/plant, spike length, spikelets/spike, seeds/plant, and grain yield/plant. In cross 'DBW14/HUW533', we observed high mean values in the F_1 and F_2 generations for days-to-maturity, plant height, effective tillers/plant, spike length, spikelets/spike, HLB-2, and HLB-3. High performance of the F_1 and F_2 populations were recorded for effective tillers/plant, spike length, and HLB-1 in cross 'GW273/HUW468'. In cross 'PBW443/HUW533', the higher value of the F_1 and F_2 population to their respective parents was observed for spike length and all three stages of HLB score.

The performance of F_2 generation higher than the F_1 generation was observed for days to 75% heading, plant height, effective tillers/plant, spike length, spikelets/spike, grains/spike, seeds/plant, 1,000-kernel weight, grain yield/plant, HLB-2, and HLB-3 in the cross 'DBW14/HUW468'. Cross 'DL788-2/PBW502' had a higher value in the F_2 population than in the F_1 population for plant height, effective tillers/plant, spike length, spikelets/spike, seeds/plant, and all three HLB stage scores. Higher mean values in the F_2 population over their F_1 were observed for days-to-maturity, plant height, grains/spike, grain weight/spike, seeds/plant, grain yield/plant, and all HLB stages in cross 'DBW14/HUW533'. In the cross 'GW 273/HUW 468', days-to-maturity and all three stages of HLB had higher mean values in the F_2 than in the F_1 population, however, in cross 'PBW443/HUW533', the higher mean values were for plant height, spike length, spikelets/spike, grains/spike, grain weight/spike, HLB-1, HLB-2, and HLB-3. These results revealed no inbreeding depression for 'genotype x environment' interactions or epistatic gene effects; the later effects were invariably noted in the present investigation.

The scaling test parameters (A, B, C, and D) from the data on different traits in all the crosses showed at least one parameter that was significantly different from 0, indicating the presence of a nonallelic interaction (Table 2, p. 73). An additive, dominance model in the analysis of data and the presence of nonallelic interaction (epistasis) in all characters in all crosses were observed. A simple, additive-dominance model was found to be adequate for spike length and grain weight/spike in all five crosses (Table 3, p. 74); for days-to-75% heading and days-to-maturity in cross 'PBW443/HUW533'; for effective tillers/plant in crosses 'DBW14/HUW533', 'GW273/HUW468', and 'PBW443/HUW533';

Table 1. Mean performance of different generations for yield and yield components in five cross combinations of bread wheat (G=generation; D75H=days-to-75% maturity; DM=days-to-maturity; PH=plant height; T/P=effective tillers/plant; SL=spike length; S/S=spikelets/spike; G/S=grains/spike; GW/S=grains/spike; TKW=1,000-kernel weight; GY/P=grain yield/plant; and HLB-2, HLB-3, and HLB-3=Helminthosporium leaf blight infection, at 77-80 d (dough stage), 83-86 d (soft dough stage), and 87-89 d (hard dough stage), respectively).

Cross	G	D75H	DM	PH (cm)	T/P	SL (cm)	S/S	G/S	GW/S (g)	S/P	TKW (g)	GY/P (g)	HLB-1	HLB-2	HLB-3	
DBW14/HUW 468 (I)	P ₁	57.00 ±0.58	117.00 ±0.58	79.33 ±2.73	7.33 ±0.88	9.00 ±0.58	18.00 ±1.15	49.33 ±2.03	1.98 ±0.14	351.00 ±4.10	41.00 ±1.15	13.66 ±0.04	12.33 ±0.33	30.33 ±3.67	45.33 ±0.33	
	P ₂	80.00 ±20.8	123.00 ±0.58	85.00 ±0.58	7.33 ±0.33	10.00 ±0.58	16.00 ±1.15	44.33 ±1.86	1.71 ±0.05	310.33 ±8.35	39.00 ±2.08	11.60 ±0.50	12.00 ±0.58	27.00 ±4.00	56.33 ±0.33	
	F ₁	78.67 ±0.88	125.00 ±0.58	83.00 ±1.15	10.00 ±0.58	11.00 ±0.58	19.33 ±1.76	45.00 ±1.15	1.26 ±0.05	447.33 ±4.91	28.00 ±0.58	12.58 ±0.06	12.33 ±0.33	23.33 ±0.33	38.00 ±3.51	
	F ₂	81.67 ±1.86	120.67 ±0.88	89.00 ±3.06	11.67 ±0.88	11.33 ±0.67	19.67 ±0.88	47.67 ±0.33	1.24 ±0.03	565.33 ±37.12	31.00 ±0.58	14.19 ±0.53	12.33 ±0.33	12.33 ±0.33	45.33 ±0.33	56.33 ±0.33
	BC ₁	63.67 ±1.76	116.00 ±1.00	80.67 ±1.33	11.00 ±0.58	11.00 ±0.58	21.00 ±0.58	48.33 ±0.88	1.06 ±0.03	546.00 ±34.43	32.00 ±0.58	13.92 ±0.26	8.67 ±3.33	19.67 ±3.33	38.00 ±3.51	
	BC ₂	81.33 ±1.76	126.33 ±1.45	82.33 ±0.88	9.67 ±0.33	10.67 ±0.88	20.33 ±0.33	52.67 ±1.76	1.39 ±0.14	519.00 ±29.48	32.33 ±0.88	17.59 ±0.30	5.33 ±3.33	13.00 ±0.00	42.00 ±3.51	
	P ₁	79.00 ±0.58	124.33 ±1.76	78.33 ±1.45	9.67 ±0.67	9.00 ±0.58	18.00 ±1.15	43.00 ±2.02	1.34 ±0.11	422.67 ±6.17	32.67 ±0.33	13.60 ±0.19	16.00 ±3.51	34.67 ±0.33	59.67 ±3.67	
	P ₂	84.00 ±0.58	125.00 ±0.58	82.67 ±2.33	9.33 ±0.33	9.00 ±0.58	18.00 ±1.15	41.00 ±1.53	1.46 ±0.06	386.00 ±6.51	36.00 ±0.58	13.62 ±0.30	5.67 ±3.67	26.33 ±3.84	49.00 ±7.51	
	F ₁	80.67 ±1.20	128.00 ±1.00	81.00 ±3.21	11.67 ±0.33	11.00 ±0.58	18.00 ±1.15	41.33 ±1.20	1.27 ±0.07	472.33 ±2.40	31.33 ±0.88	14.73 ±0.35	12.33 ±0.33	27.33 ±3.84	52.67 ±3.33	
	F ₂	76.00 ±0.58	125.00 ±0.58	94.00 ±1.53	14.00 ±0.58	12.00 ±0.58	22.00 ±1.15	35.00 ±1.15	1.00 ±0.01	488.33 ±3.53	28.67 ±0.67	13.70 ±0.12	16.00 ±3.51	56.67 ±6.06	74.00 ±4.00	
	BC ₁	78.67 ±0.88	131.00 ±0.58	84.00 ±1.53	11.00 ±0.58	10.00 ±0.58	20.00 ±0.58	43.00 ±0.58	1.08 ±0.04	455.33 ±8.84	30.67 ±0.88	11.33 ±0.12	2.00 ±3.51	23.33 ±0.33	53.00 ±7.00	
	BC ₂	86.33 ±1.86	126.67 ±0.88	88.00 ±3.61	9.00 ±0.58	11.00 ±0.58	21.33 ±0.67	50.00 ±3.21	1.26 ±0.07	467.20 ±19.61	31.67 ±0.88	11.87 ±0.74	2.00 ±3.52	23.00 ±0.58	45.67 ±6.06	
DBW14/HUW 533 (III)	P ₁	58.67 ±0.88	117.67 ±0.88	82.00 ±1.73	10.67 ±0.33	9.67 ±0.33	18.33 ±1.45	44.33 ±0.88	1.72 ±0.01	467.33 ±11.62	38.67 ±0.33	18.43 ±0.36	12.00 ±3.51	20.00 ±3.51	34.67 ±6.39	
	P ₂	84.00 ±1.15	124.67 ±1.20	105.67 ±1.45	10.00 ±0.58	8.00 ±0.58	17.33 ±1.76	40.67 ±0.33	1.24 ±0.09	404.67 ±21.42	29.67 ±0.69	11.34 ±0.88	9.00 ±0.27	27.00 ±3.51	45.67 ±0.33	
	F ₁	78.33 ±0.88	127.33 ±0.88	99.00 ±1.15	12.00 ±0.58	11.00 ±0.58	20.00 ±1.15	36.67 ±1.20	0.95 ±0.03	428.00 ±6.56	31.67 ±0.33	11.15 ±0.19	5.00 ±3.51	16.33 ±3.33	38.67 ±3.18	
	F ₂	76.00 ±0.58	128.33 ±0.88	111.33 ±1.20	11.67 ±0.33	10.00 ±0.58	20.00 ±1.15	41.67 ±1.45	1.06 ±0.03	468.33 ±9.35	31.67 ±0.33	11.74 ±0.34	5.33 ±3.33	34.67 ±0.33	56.67 ±0.33	
	BC ₁	77.33 ±0.88	126.33 ±0.88	95.67 ±1.86	11.00 ±0.58	10.00 ±0.58	20.00 ±0.58	43.67 ±2.40	1.05 ±0.06	464.33 ±8.41	31.00 ±1.00	11.70 ±0.30	1.67 ±0.33	16.00 ±3.00	56.00 ±0.58	
	BC ₂	87.00 ±0.58	126.00 ±0.58	93.00 ±1.53	12.33 ±1.20	10.00 ±0.33	20.00 ±0.58	38.67 ±4.26	1.07 ±0.12	466.33 ±5.36	32.67 ±1.20	12.36 ±0.10	5.33 ±3.33	16.33 ±3.33	42.67 ±3.84	

Table 1 (continued). Mean performance of different generations for yield and yield components in five cross combinations of bread wheat (G=generation; D75H=days-to-75% maturity; DM=days-to-maturity; PH=plant height; T/P=effective tillers/plant; SL=spike length; S/S=spikelets/spike; G/S=grains/spike; GW/S=grain weight/spike; TKW=1,000-kernel weight; GY/P=grain yield/plant; and HLB-2, HLB-2, and HLB-3=Helminthosporium leaf blight infection, at 77–80 d (dough stage), 83–86 d (soft dough stage), and 87–89 d (hard dough stage), respectively).

Cross	G	D75H	DM	PH (cm)	T/P	SL (cm)	S/S	G/S	GW/S (g)	S/P	TKW (g)	GY/P (g)	HLB-1	HLB-2	HLB-3	
GW273/HUW 468 (IV)	P ₁	80.00 ±2.52	127.33 ±0.88	89.67 ±2.33	9.00 ±0.58	8.33 ±0.88	20.00 ±1.15	38.33 ±0.67	1.05 ±0.06	339.67 ±21.15	27.67 ±1.20	8.91 ±0.21	9.00 ±7.00	30.33 ±7.33	56.33 ±0.67	
	P ₂	81.33 ±0.88	124.67 ±0.33	86.67 ±0.88	10.33 ±0.33	10.67 ±0.33	17.33 ±0.67	45.00 ±1.53	1.54 ±0.05	464.00 ±4.04	33.67 ±0.33	15.36 ±0.05	5.00 ±3.51	15.67 ±3.67	42.67 ±3.84	
	F ₁	81.33 ±0.88	124.00 ±0.58	91.00 ±0.58	12.00 ±0.58	12.00 ±0.58	12.00 ±0.58	22.00 ±1.15	39.00 ±0.58	1.14 ±0.33	470.33 ±31.42	29.33 ±0.33	13.74 ±0.68	12.33 ±0.33	27.33 ±3.33	56.33 ±0.33
	F ₂	76.00 ±0.58	125.33 ±1.20	89.33 ±1.20	11.33 ±0.67	10.67 ±0.33	20.00 ±1.15	38.00 ±1.15	1.08 ±0.03	430.67 ±20.85	29.00 ±0.33	29.00 ±0.33	12.17 ±0.40	20.33 ±3.67	49.67 ±3.71	70.33 ±2.85
	BC ₁	82.00 ±0.58	126.67 ±0.88	86.67 ±0.88	10.33 ±0.33	11.00 ±0.58	22.00 ±1.15	38.00 ±2.31	0.91 ±0.05	405.00 ±7.51	30.00 ±1.15	30.00 ±1.15	9.69 ±0.11	8.33 ±3.67	20.00 ±3.51	56.67 ±6.06
	BC ₂	84.33 ±1.20	128.00 ±0.58	85.33 ±1.20	10.00 ±0.58	12.00 ±0.58	22.00 ±1.15	35.33 ±1.76	1.19 ±0.09	338.00 ±3.51	33.67 ±0.88	33.67 ±0.88	11.31 ±0.14	2.00 ±0.00	20.00 ±3.51	52.33 ±3.67
	P ₁	83.00 ±1.53	125.13 ±0.47	79.67 ±1.20	9.67 ±0.33	7.67 ±0.33	17.33 ±1.76	35.33 ±2.60	1.10 ±0.08	349.00 ±16.48	31.00 ±1.00	31.00 ±1.00	10.16 ±0.18	12.33 ±6.06	30.67 ±7.17	59.33 ±7.17
	P ₂	84.67 ±1.45	125.80 ±1.17	106.00 ±1.53	11.00 ±0.58	8.67 ±0.88	18.00 ±1.15	40.33 ±0.67	1.15 ±0.01	442.33 ±14.50	28.67 ±0.33	28.67 ±0.33	12.24 ±0.22	1.33 ±0.33	15.67 ±3.67	45.67 ±6.06
PBW443/HUW 533 (V)	F ₁	84.67 ±0.88	126.20 ±0.81	81.00 ±1.15	10.33 ±0.67	10.67 ±0.88	18.00 ±1.15	36.00 ±2.00	1.05 ±0.07	386.33 ±3.53	29.00 ±0.58	10.89 ±0.11	5.33 ±3.33	34.33 ±0.33	52.67 ±7.17	
	F ₂	82.33 ±0.88	125.73 ±0.87	94.33 ±2.91	10.00 ±0.58	11.00 ±0.58	20.00 ±1.15	37.00 ±2.08	1.07 ±0.08	361.33 ±12.88	29.33 ±1.33	10.19 ±0.18	16.67 ±3.67	53.33 ±3.67	63.33 ±3.18	
	BC ₁	83.00 ±1.53	125.20 ±0.53	68.67 ±0.67	10.67 ±0.88	10.00 ±0.58	18.00 ±1.15	31.33 ±1.20	0.97 ±0.04	341.33 ±22.92	30.33 ±0.33	10.18 ±0.64	8.67 ±3.33	37.67 ±7.33	59.67 ±3.67	
	BC ₂	86.67 ±0.88	125.47 ±0.87	105.33 ±0.88	12.33 ±0.87	10.67 ±0.88	16.00 ±1.15	34.33 ±1.45	0.99 ±0.03	408.00 ±13.11	29.33 ±0.33	29.33 ±0.33	11.69 ±0.45	1.67 ±0.33	23.33 ±0.33	49.33 ±3.33

for spikelets/spike in crosses ‘DBW14/HUW468’, ‘DBW14/HUW533’, and ‘GW273/HUW468’; for 1,000-kernel weight and grain yield/plant in cross ‘PBW443/HUW533’ (Singh et al. 1998; Dhillon et al. 2002; Shekhawat et al. 2006). The Chi-square (c²) value was significant for rest of the characters and indicated the complexity of the genetic control of these traits in bread wheat, which may be attributed to epistasis between interacting genes in bread wheat (Singh et al. 1984; Simon et al. 1994; Mostafavi et al. 2005). Differences among the results may be due to differences in the genetic backgrounds. We emphasize that the inferences drawn from the generation mean analysis in crops were specific to the population under study and can not be correlated to other crops.

A six-parameter model was applied to all traits in all crosses (Mohammad et al. 1991). The m, d, and h components also were estimates that revealed that additive (d) and dominance (h) both components were significant in all five crosses for seeds/plant. For days-to-75% heading in cross ‘DBW14/HUW468’ and ‘DBW14/HUW533’; for days-to-maturity in cross ‘DBW14/HUW533’; for plant height in all the crosses except ‘DBW14/HUW468’; for grains/spike in crosses ‘DBW14/HUW533’, ‘GW273/HUW468’, and ‘PBW443/HUW533’; for 1,000-kernel weight in crosses ‘DL788-2/PBW502’ and ‘DBW14/HUW533’; for grain yield/plant in cross ‘DBW14/HUW533’; for all the three stages of HLB in crosses ‘DBW14/HUW533’ and

Table 2. Estimation of scaling tests for testing the adequacy of additive-dominance model for different traits in five crosses of wheat (P=scaling test parameters (A, B, C, and D); D75H=days-to-75% maturity; DM=days-to-maturity; PH=plant height; T/P=effective tillers/plant; SL=spike length; S/S=spikelets/spike; G/S=grains/spike; GW/S=gram weight/spike; S/P=seeds/plant; TKW=1,000-kernel weight; GY/P=P=grain yield/plant; and HLB-2, HLB-3=Helminthosporium leaf blight infection, at 77–80 d (dough stage), 83–86 d (soft dough stage), and 87–89 d (hard dough stage), respectively).

Cross	P	D75% ^H	DM	PH (cm)	T/P	SL (cm)	S/S	G/S	GW/S	S/P	TKW	GY/P (g)	HLB-1	HLB-2	HLB-3	
DBW14/HUW 468 (I)	A	-8.00* ±3.68	-10.00** ±2.20	-1.00 ±3.98	4.66** ±1.56	2.00 ±1.41	4.66 ±2.40	2.33 ±2.92	-1.12** ±0.16	293.33** ±69.15	-5.00** ±1.73	1.59** ±0.53	-7.33 ±6.68	-14.33 ±7.61	-7.33 ±7.85	
	B	4.00 ±4.18	4.67 ±3.01	-3.33 ±2.18	2.00* ±0.94	0.33 ±1.94	5.33* ±2.21	16.00** ±4.14	-0.20 ±0.29	280.33** ±59.75	-2.33 ±2.78	10.99** ±0.78	-13.66* ±6.69	-24.33** ±4.01	-10.33 ±7.85	
	C	32.33** ±7.93	-7.33 ±3.80	25.67* ±12.74	12.00** ±3.82	4.33 ±3.01	6.00 ±5.24	7.00 ±3.82	-1.24** ±0.21	704.99** ±149.10	-12.00** ±3.51	6.35** ±2.17	0.33 ±1.63	77.33** ±5.62	77.33** ±5.62	47.66** ±7.16
	D	18.33** ±4.47	-1.00 ±2.49	15.00* ±6.31	2.66 ±1.88	1.00 ±1.69	-2.00 ±1.88	-5.66** ±2.08	0.04 ±0.15	65.66 ±86.98	-2.33 ±1.56	-3.12** ±1.13	10.66* ±4.76	58.00** ±3.39	58.00** ±3.39	32.66** ±5.01
DL788-2/ PBW 502 (II)	A	-2.33 ±2.21	9.66** ±2.33	8.66 ±4.66	0.66 ±1.37	0.00 ±0.00	4.00* ±1.63	1.66 ±2.62	-0.45** ±0.15	15.66 ±18.87	-2.66 ±2.00	-5.67** ±0.46	-21.00* ±7.61	-15.33** ±3.91	-6.33 ±14.85	
	B	8.00* ±3.94	0.33 ±2.10	12.33 ±8.23	-3.00* ±1.24	2.00 ±1.41	6.66** ±2.10	17.66* ±6.71	-0.21 ±0.16	76.06 ±39.82	-4.00* ±1.97	-4.62** ±1.54	-14.00** ±3.68	-7.66 ±5.43	-10.33 ±14.64	
	C	-20.33** ±3.43	-5.33 ±3.57	53.00** ±9.28	13.66** ±2.51	8.00** ±2.70	16.00** ±5.41	-26.66** ±5.79	-1.32** ±0.19	200.00** ±17.39	-16.66** ±3.21	-1.90* ±0.92	14.33 ±14.98	111.00** ±25.73	82.00** ±19.24	
	D	-13.00** ±2.35	-7.66** ±1.56	16.00** ±4.96	8.00** ±1.41	3.00* ±1.41	2.66 ±2.40	-23.00** ±4.00	-0.32** ±0.08	54.13* ±22.63	-5.00** ±1.82	4.19** ±0.78	24.66** ±7.77	67.00** ±12.13	49.33** ±12.23	
DBW14/HUW533 (III)	A	17.66** ±2.16	7.66** ±2.16	10.33* ±4.25	-0.66 ±1.33	0.66 ±1.33	1.66 ±2.18	6.33 ±5.03	6.33 ±5.03	33.33 ±21.47	-8.33** ±2.05	-6.18** ±0.72	-6.67 ±5.01	-4.33 ±7.71	38.67* ±7.13	
	B	11.66** ±1.85	0.00 ±0.00	-18.66** ±3.57	2.66 ±2.53	1.00 ±0.81	2.66 ±2.40	0.00 ±0.00	0.00 ±8.60	100.00** ±24.83	4.00 ±2.58	2.23** ±0.39	-3.33 ±8.31	-10.66 ±8.23	1.00 ±8.32	
	C	4.66 ±3.24	16.33** ±4.21	59.66** ±5.79	2.00 ±1.88	0.33 ±2.66	4.33 ±5.64	8.33 ±6.35	8.33 ±6.35	145.33** ±46.52	-5.00* ±1.76	-5.11** ±1.46	-2.67 ±15.86	59.00** ±8.41	69.00** ±9.11	
	D	-12.33** ±1.56	4.33* ±2.05	34.00** ±3.39	0.00 ±1.49	0.00 ±1.29	0.00 ±2.44	1.00 ±5.68	1.00 ±5.68	6.00 ±21.19	-0.33 ±1.69	-0.58 ±0.74	3.67 ±7.46	37.00** ±4.53	14.66 ±3.90	
GW273/HUW468 (IV)	A	2.66 ±2.90	2.00 ±2.05	-7.33* ±2.98	-0.33 ±1.05	1.66 ±1.56	2.00 ±2.82	-1.33 ±4.70	6.33 ±5.03	33.33 ±21.47	-8.33** ±2.05	-6.18** ±0.72	-6.67 ±5.01	-4.33 ±7.71	38.67* ±7.13	
	B	6.00* ±2.70	7.33** ±1.33	-7.00* ±2.62	-2.33 ±1.33	1.33 ±1.33	4.66 ±2.66	-13.33** ±3.88	0.00 ±8.60	100.00** ±24.83	4.00 ±2.58	2.23** ±0.39	-3.33 ±8.31	-10.66 ±8.23	1.00 ±8.32	
	C	-20.00** ±3.94	1.33 ±5.03	-1.00 ±5.53	2.00 ±2.98	-0.33 ±2.00	-1.33 ±5.33	-9.33 ±5.04	8.33 ±6.35	145.33** ±46.52	-5.00* ±1.76	-5.11** ±1.46	-2.67 ±15.86	59.00** ±8.41	69.00** ±9.11	
	D	-14.33** ±1.76	-4.00 ±2.62	6.66* ±2.82	2.33 ±1.49	-1.66 ±1.05	-4.00 ±2.82	2.66 ±3.71	1.00 ±5.68	6.00 ±21.19	-0.33 ±1.69	-0.58 ±0.74	3.67 ±7.46	37.00** ±4.53	14.66 ±3.90	
PBW443/HUW533 (V)	A	-1.66 ±3.52	-0.93 ±1.41	-23.33** ±2.13	1.33 ±1.91	1.66 ±1.49	0.66 ±3.12	-8.66* ±4.06	-0.21 ±0.14	-53.00 ±48.84	0.67 ±1.33	-0.70 ±1.29	-0.33 ±9.60	10.33 ±16.32	7.33 ±12.51	
	B	4.00 ±2.44	-1.06 ±2.24	23.66** ±2.60	3.33 ±1.97	2.00 ±2.16	-4.00 ±2.82	-7.66* ±3.59	-0.21 ±0.10	-12.67 ±30.17	1.00 ±0.94	0.24 ±0.92	-3.33 ±3.41	-3.33 ±3.74	0.33 ±11.51	
	C	-7.66 ±4.47	-0.40 ±4.02	29.66* ±12.00	-1.33 ±2.74	6.33* ±3.05	8.66 ±5.57	0.33 ±9.62	-0.07 ±0.37	-119.00* ±56.42	-0.33 ±5.55	-3.43** ±0.80	42.33** ±17.21	98.33** ±16.74	43.00* ±21.34	
	D	-5.00* ±2.49	0.80 ±2.00	14.66* ±5.91	-3.00 ±1.69	1.33 ±1.56	6.00* ±2.82	8.33 ±4.57	0.17 ±0.17	-26.67 ±36.88	-1.00 ±2.70	-1.49 ±0.85	23.00* ±8.06	45.67** ±10.37	17.67* ±8.06	

Table 3. Estimation of adequacy for simple additive-dominance model in different traits of five crosses of wheat (P=parameter; D75H=days-to-75% maturity; DM=days-to-maturity; PH=plant height; T/ P=effective tillers/plant; SL=spike length; S/S=spikelets/spike; G/S=grains/spike; GW/S=gram weight/spike; S/P=seeds/plant; TKW=1,000-kernel weight; GY/P=gram yield/plant; and HLB-2, and HLB-3=Helminthosporium leaf blight infection, at 77–80 d (dough stage), 83–86 d (soft dough stage), and 87–89 d (hard dough stage), respectively).

HLB-3Cross	P	D75% <i>H</i>	DM	PH (cm)	T/P	SL (cm)	S/S	G/S	GW/S (g)	S/P	TKW	GY/P (g)	HLB 1	HLB-2	HLB-3
DBW14/HUW 468 (I)	m	69.19** ±0.64	119.47** ±0.64	82.66** ±0.64	8.07** ±0.64	9.76** ±0.64	17.76* ±0.64	48.11** ±0.64	1.72** ±0.64	385.31** ±0.64	39.21** ±0.64	13.55** ±0.64	10.94** ±0.64	28.66** ±0.64	51.19** ±0.64
	d	-12.73** ±0.63	-4.46 ±0.63	-2.60** ±0.63	0.26 ±0.63	0.33 ±0.63	0.93 ±0.63	1.13 ±0.63	0.04 ±0.63	21.80** ±0.63	0.73 ±0.63	0.09 ±0.63	0.79 ±0.63	2.66** ±0.63	-5.20** ±0.63
	h	10.86** ±1.18	4.47** ±1.18	1.33 ±1.18	3.41** ±1.18	1.76 ±1.18	3.09* ±1.18	-0.54 ±1.18	-0.69 ±1.18	170.98** ±1.18	-12.78** ±1.18	0.88 ±1.18	-1.05 ±1.18	-5.33** ±1.18	-12.47** ±1.18
	c ²	76.720**	24.854**	40.877**	8.188*	7.338	42.723**	0.232	34.374.200**	8.590*	20.198**	39.994**	570.667**	180.243**	
	m	81.23** ±0.64	125.09** ±0.64	83.29** ±0.64	9.76** ±0.64	9.35** ±0.64	15.560*	42.35** ±0.64	1.32* ±0.64	415.61** ±0.64	33.45** ±0.64	12.95** ±0.64	10.86** ±0.64	32.41** ±0.64	55.76** ±0.64
DL788-2/PBW 502 (II)	d	-3.53** ±0.63	0.60 ±0.63	-2.53** ±0.63	0.53 ±0.63	-0.20 ±0.63	0.60 ±0.63	-0.60 ±0.63	0.085 ±0.63	12.29** ±0.63	-1.53* ±0.63	-0.114 ±0.63	6.13** ±0.63	3.40** ±0.63	5.73** ±0.63
	h	-1.09 ±1.18	3.76** ±1.18	3.29** ±1.18	2.43* ±1.18	2.35 ±1.18	1.09 ±1.18	-0.31 ±1.18	-0.21 ±1.18	79.27** ±1.18	-3.88** ±1.18	0.458 ±1.18	-1.80 ±1.18	-1.25 ±1.18	-0.23 ±1.18
	c ²	39.638**	20.616**	132.491**	12.805*	3.311	15.560*	115.178**	0.093	2.294.853**	13.167*	8.000*	136.687**	795.466**	430.449**
	m	73.19** ±0.64	122.09** ±0.64	95.09** ±0.64	10.50** ±0.64	8.86** ±0.64	18.21** ±0.64	43.11** ±0.64	1.42** ±0.64	448.11** ±0.64	33.76** ±0.64	14.50** ±0.64	6.33** ±0.64	24.35** ±0.64	44.52** ±0.64
	d	-12.06** ±0.63	-2.73** ±0.63	-8.93** ±0.63	0.019 ±0.63	0.66 ±0.63	0.40 ±0.63	2.46** ±0.63	0.18 ±0.63	24.66** ±0.63	3.26** ±0.63	2.70** ±0.63	-2.33** ±0.63	-2.86** ±0.63	-1.73** ±0.63
DBW14/HUW533 (III)	h	8.86** ±1.18	7.09** ±1.18	6.43** ±1.18	1.84 ±1.18	2.19 ±1.18	2.54* ±1.18	-5.21** ±1.18	-0.59 ±1.18	4.117** ±1.18	-2.90** ±1.18	-4.12** ±1.18	-2.67** ±1.18	-6.31** ±1.18	2.86** ±1.18
	c ²	68.276**	18.838**	294.894**	1.464	0.287	1.756	8.501*	0.061	2.114.602**	17.060**	8.794*	8.388*	240.422**	393.443**
	m	80.58** ±0.64	126.58** ±0.64	87.29** ±0.64	9.56** ±0.64	9.66** ±0.64	19.01** ±0.64	40.52** ±0.64	1.23* ±0.64	385.99** ±0.64	30.98** ±0.64	11.46** ±0.64	7.16** ±0.65	24.67** ±0.64	51.92** ±0.64
	d	-1.00* ±0.63	0.80 ±0.63	1.46* ±0.63	-0.46 ±0.63	-1.13* ±0.63	1.06* ±0.63	-2.13** ±0.63	-0.23 ±0.63	-36.33** ±0.63	-3.13** ±0.63	-2.90** ±0.63	2.86** ±0.62	5.86** ±0.63	6.33** ±0.63
	h	0.58 ±1.20	-1.41 ±1.19	1.96* ±1.19	2.23 ±1.20	2.66** ±1.18	3.68** ±1.19	-3.80** ±1.19	-0.19 ±1.19	52.67** ±1.19	-1.02 ±1.20	0.94 ±1.18	5.52** ±1.20	6.00** ±1.19	9.25** ±1.20
PBW443/HUW533 (V)	c ²	35.421**	9.432*	16.047**	1.416	0.788	30.243**	0.034	11.848.610**	6.645*	7.909*	161.298**	639.733**	236.088**	
	m	83.74** ±0.64	125.34** ±0.64	93.72** ±0.64	10.56** ±0.64	8.56** ±0.64	17.72** ±0.64	36.88** ±0.64	1.09* ±0.64	388.47** ±0.64	29.92** ±0.65	11.07** ±0.64	7.86** ±0.65	26.47** ±0.65	54.21** ±0.65
	d	-1.39* ±0.63	-0.32 ±0.63	-17.86** ±0.63	-0.86 ±0.63	-0.53 ±0.63	0.13 ±0.63	-2.60** ±0.63	-0.025 ±0.63	-50.53** ±0.63	1.13* ±0.63	-1.13* ±0.62	5.80** ±0.63	8.86** ±0.63	7.53** ±0.63
	h	0.74 ±1.18	0.60 ±1.19	-10.94** ±1.18	0.23 ±1.18	2.90** ±1.21	0.39 ±1.19	-2.78** ±1.19	-0.099 ±1.18	-16.86** ±1.18	-0.74 ±1.18	-0.43 ±1.19	-0.47 ±1.18	14.47** ±1.19	1.82* ±1.18
	c ²	7.466	0.298	265.772**	2.527	2.138	8.216*	21.923**	0.0138	895.576**	0.266	0.644	101.076**	489.965**	90.279**

‘GW273/HUW468’; and for HLB-2 and HLB-3 in crosses ‘DBW14/HUW468’ and ‘PBW443/HUW533’. Additive (d) components were significant for days-to-75% heading in ‘DL788-2/PBW502’, ‘GW273/HUW468’, and ‘PBW443/HUW533’; for 1,000-kernel weight in crosses ‘GW273/HUW468’ and ‘PBW443/HUW533’; for grain yield/plant in crosses ‘GW273/HUW468’ and ‘PBW443/HUW533’; for HLB-1, HLB-2, and HLB-3 in cross ‘DL788-2/PBW502’; and HLB-1 in cross ‘PBW443/HUW533’. Dominance (h) components were important for days-to-maturity and effective tillers/plant in crosses ‘DBW14/HUW468’ and ‘DL788-2/PBW502’ and for 1,000-kernel weight in cross ‘DBW14/HUW 468’. Both main ef-

fects d and h are important in the inheritance of these traits in wheat (Vimal et al. 1999; Sharma et al. 2003).

The analysis of gene effects revealed that interactions played a major role in the inheritance of grain yield and its related components (Table 4, p. 75-76). Additive gene effects were observed for days-to-75% heading in all the crosses except 'PBW443/HUW533'; for days-to-maturity in crosses 'DBW14/HUW468' and 'DL788-2/PBW502'; for plant height in cross 'PBW443/HUW533'; for effective tillers/plant in crosses 'DBW14/HUW468' and 'DL788-2/PBW502'; for grains/spike in crosses 'DBW14/HUW468' and 'DL788-2/PBW502'; and for seeds/plant in crosses 'GW 273/HUW468' and 'PBW443/HUW533'. Dominance effects were significant for days-to-75% heading in all crosses except 'PBW443/HUW533'; for days-to-maturity in cross 'DL788-2/PBW502'; for plant height in all crosses except 'DBW14/HUW468'; for effective tillers/plant in cross 'DL788-2/PBW502'; for spikelets/spike in cross 'PBW443/HUW533'; for grains/spike in crosses 'DBW14/HUW468', 'DL788-2/PBW502', and 'PBW443/HUW533'; for seeds per plant in

Table 4. Estimation of the components of generation mean analysis using six-parameter model of Hayman (1958) for 16 traits in five crosses of bread wheat (m = mean effect, d = additive effect, h = dominance effect, i = 'additive x additive' interaction, j = 'additive x dominant' interaction, l = 'dominant x dominant' interaction, * and ** equal significance at 5% and 1%, respectively; D = duplicate and C = complimentary).

Cross/ character	Gene effect						Type of epistasis
	m	d	h	i	j	l	
DBW14/HUW 468 (I)							
Days-to-75% heading	81.66**±1.85	-17.66**±2.49	-26.49**±9.05	-36.66**±8.94	-6.16**±2.71	40.99**±12.74	D
Days-to-maturity	120.66**±0.88	-10.33**±1.76	7.00±5.03	2.00±4.98	-7.33**±1.81	3.33±8.01	C
Plant height (cm)	89.00**±3.05	-1.67±1.59	-29.16±12.76	-30.00**±12.63	1.16±2.12	34.33**±14.25	D
Effective tillers/plant	11.67**±0.88	1.33**±0.67	-2.67±3.84	-5.33±3.77	-1.33±0.81	-1.33±4.67	C
Grains/spike	47.67**±0.33	-4.33**±1.97	9.49**±4.53	11.33**±4.16	-6.83**±2.40	-29.67**±8.76	D
Seeds/plant	56.53**±37.12	27.00**±45.32	-14.83±174.10	-131.33**±173.97	6.50±45.56	-442.33**±234.74	C
1,000-kernel weight (gm)	31.00**±0.58	-0.33±1.05	-7.33**±3.39	4.67±3.12	-1.33±1.58	2.67±5.48	D
Grain yield/plant (gm)	14.19**±0.53	-3.67**±0.40	6.19**±2.27	6.24**±2.26	-4.69**±0.47	-18.83**±2.70	D
HLB -1	12.33**±0.33	3.33±4.71	-21.16**±9.53	-21.33**±9.52	3.16±4.72	42.33**±18.92	D
HLB -2	45.33**±0.33	6.67**±3.33	-121.33**±7.32	-116.00**±6.79	4.99±4.29	154.67**±14.47	D
HLB -3	56.33**±0.33	-4.00±4.96	-78.17**±10.62	-65.33**±10.02	1.50±4.97	82.99**±21.12	D
DL788-2/PBW502 (II)							
Days-to-75% heading	76.00**±0.57	-7.67**±2.05	25.17**±4.88	26.00**±4.71	-5.17**±2.09	-31.67**±8.90	D
Days-to-maturity	125.00**±0.58	4.33**±1.05	18.67**±3.41	15.33**±3.12	4.67**±1.40	-25.33**±5.53	D
Plant height (cm)	94.00**±1.52	-4.00±3.91	-31.50**±10.53	-32.00**±9.93	-1.83±4.14	11.00±18.20	D
Effective tillers/plant	14.00**±0.58	2.00**±0.82	-13.83**±2.87	-16.00**±2.82	1.83**±0.89	18.33**±4.12	D
Grains/spike	22.00**±1.15	-1.33±0.67	-5.33±5.01	-5.33±4.81	-1.33±1.05	-5.33±6.03	C
Spikelets/spike	35.00**±1.15	-7.00**±3.26	45.33**±8.18	46.00**±8.00	-8.00**±3.50	-65.33**±14.29	D
Seeds/plant	488.33**±3.52	-11.87±21.51	-40.27±45.56	-108.27**±45.27	-30.19±21.97	16.53±87.78	D
1,000-kernel weight (gm)	28.66**±0.67	-1.00±1.24	7.00±3.76	10.00**±3.65	0.67±1.25	-3.33±5.93	D
Grain yield/plant (gm)	13.69**±0.12	-0.53±0.74	-7.27**±1.61	-8.38**±1.56	-0.52±0.76	18.68**±3.12	D
HLB -1	16.00**±3.51	3.33±3.33	-49.50**±15.76	-49.33**±15.54	-3.50±4.22	84.33**±20.06	D
HLB -2	56.67**±6.06	0.33±0.33	-137.17**±24.64	-134.00**±24.26	-3.83**±1.95	157.00**±25.77	D
HLB -3	74.00**±4.00	7.33±9.26	-100.33**±25.05	-98.67**±24.47	1.99±10.15	115.33**±41.74	D
DBW14/HUW 533 (III)							
Days-to-75% heading	76.00**±0.57	-9.67**±1.05	31.67**±3.32	24.67**±3.12	3.00**±1.28	-54.00**±5.32	D
Days-to-maturity	128.33**±0.88	0.33±1.05	-2.50±4.26	-8.67**±4.10	3.83**±1.29	0.99±5.96	D
Plant height (cm)	111.33**±1.20	2.67±2.40	-62.83**±6.98	-68.00**±6.79	14.50**±2.65	76.33**±11.22	D
Grains/spike	41.66**±1.45	5.00±4.88	-7.83±11.44	-2.00±11.37	3.17±4.91	-4.33±20.55	C
Seeds/plant	468.33**±9.35	-2.00±9.97	-20.00**±44.59	-12.00**±42.39	-33.33**±15.74	-121.33**±61.30	C
1,000-kernel weight (gm)	31.66**±0.33	-1.67±1.56	-1.83±3.44	0.67±3.39	-6.17**±1.63	3.67±6.49	D
Grain yield/plant (gm)	11.74**±0.34	-0.67**±0.31	-2.59±1.51	1.15±1.48	-4.21**±0.38	2.80±1.93	D
HLB -1	5.33**±3.33	-3.67±3.34	-9.33±15.52	-7.33±14.92	-1.67±4.16	17.33±20.76	D
HLB -2	34.67**±0.33	-0.33±4.48	-81.17**±9.97	-74.00**±9.06	3.16±5.12	89.00**±19.81	D
HLB -3	56.67**±0.33	13.33**±3.84	-30.83**±9.01	-29.33**±7.80	18.83**±5.00	-10.33**±17.87	C

crosses 'DBW14/HUW533' and 'GW273/HUW468'; for HLB-1 in all the crosses except 'DBW14/HUW533'; and for HLB-2 and HLB-3 in all five crosses.

The digenic interactions 'additive x additive' (i) and 'dominant x dominant' (l) had an important role in controlling the inheritance of yield and its related components. 'Additive x additive', 'additive x dominant', and 'dominant x dominant' interactions were significant for days-to-75% heading in the 'DBW14/HUW468', 'DL788-2/PBW502', and 'DBW14/HUW533' crosses; whereas, 'additive x additive' and 'dominant x dominant' components were significant for days-to-75% heading in the 'GW273/HUW468' cross. The 'dominant x dominant' component was predominant for days-to-75% heading in all crosses except 'PBW443/HUW533'. For days-to-maturity, 'additive x dominant' effects were significant in crosses 'DBW14/HUW468', 'DL788-2/PBW502', and 'DBW14/HUW533'; however, 'additive x additive' effects were more important in crosses 'DL788-2/PBW502' and 'DBW14/HUW533' and a 'dominant x dominant' gene interaction was significant in crosses 'DL788-2/PBW502' and 'GW273/HUW468'. For plant height, all

types of gene effects were found significant in cross 'DBW14/HUW533', 'additive x additive' and 'dominant x dominant' effects were noticed in crosses 'DBW14/HUW468' and 'GW273/HUW468', and an 'additive x additive' gene interaction was found significant in cross DL788-2/PBW502 (Amawate et al. 1995). Effective tillers/plant had all types of gene effects were found significant only in cross 'DL788-2/PBW502' and 'dominant x dominant' predominated in cross 'DL788-2/PBW502'. Spikelets/spike were nonsignificant for all types of gene effect in all the crosses except 'PBW443/HUW533'. For grains/spike, 'additive x additive', 'additive x dominant' and dominant components were significant in crosses 'DBW14/HUW468' and 'DL788-2/PBW502', 'additive x dominant' and 'dominant x dominant' effects were significant in cross 'GW273/HUW468', 'additive x dominant' components were significant in cross PBW443/HUW533, and a 'dominant x dominant' component was predominant in all other crosses except 'DBW14/HUW533'. All types of epistasis were significant for seeds/plant in cross 'GW273/HUW468' and 'additive x additive' and 'dominant x dominant' components were predominant in crosses 'DBW14/HUW468', 'DBW14/HUW533', and 'GW273/HUW468'. For 1,000-kernel weight, the 'additive x additive' components were significant in crosses 'DL788-2/

Table 4 (continued). Estimation of the components of generation mean analysis using six-parameter model of Hayman (1958) for 16 traits in five crosses of bread wheat (m = mean effect, d = additive effect, h = dominance effect, i = additive x additive interaction, j = additive x dominant interaction, l = dominant x dominant interaction; * and ** equal significance at 5% and 1%, respectively; D = duplicate and C = complimentary).

Cross/ character	Gene effect						Type of epistasis	
	m	d	h	i	j	l		
GW273/HUW 468 (IV)								
Days-to-75% heading	76.0**±0.58	-2.33**±1.33	29.33**±3.87	28.67**±3.52	-1.67±1.88	-37.33**±6.63	D	
Days-to-maturity	125.33**±1.20	-1.33±1.05	5.99±5.30	7.99±5.24	-2.67±1.15	-17.33**±6.56	D	
Plant height (cm)	89.33**±1.20	1.33±1.49	-10.50**±5.28	-13.33**±5.65	-0.16±1.94	27.67**±8.13	D	
Grains/spike	38.00**±1.15	2.67±2.90	-8.00±7.49	-5.33±7.42	6.00**±3.02	20.00**±12.67	D	
Seeds/plant	430.67**±20.85	67.00**±8.28	-168.17**±91.29	-236.67**±85.03		495.00**±111.67	D	
1,000-kernel weight (gm)	29.00**±0.33	-3.67**±1.45	10.00**±2.99	11.33**±2.90	-0.67±1.58	-18.67**±5.98	D	
Grain yield/plant (gm)	12.16**±0.40	-1.62**±0.17	-5.06**±1.77	-6.67**±1.64	1.61**±0.20	16.43**±2.21	D	
HLB-1	20.33**±3.67	6.33±3.67	-55.33**±16.86	-60.67**±16.39	4.33±5.36	78.67**±22.18	D	
HLB-2	49.67**±3.71	0.00±4.96	-114.33**±18.62	-118.67±17.86	-7.33±6.43	139.33**±26.95	D	
HLB-3	70.33**±2.84	4.33±7.08	-56.50**±18.29	-63.33**±18.18	-2.50±7.35	57.00**±30.80	D	
PBW443/HUW 533 (V)								
Plant height (cm)	94.33**±2.90	-36.67**±1.10	-41.17**±11.92	-29.33**±11.83	-23.50**±1.47	29.00**±12.79	D	
Spikelets/spike	20.00**±1.15	2.00±1.63	-11.67**±5.86	-12.00**±5.65	2.33±1.94	15.33**±8.58	D	
Grains/spike	37.00**±2.08	-2.99±1.88	-18.50**±9.45	-16.67**±9.14	-0.50±2.31	33.00**±12.22	D	
Seeds/plant	361.33**±12.87	-67.66**±26.41	43.83±74.67	53.33±73.77	-20.17±28.59	12.33±119.76	C	
HLB-1	16.67**±3.67	7.00**±3.34	-47.50**±16.74	-46.00**±16.12	1.50±4.52	49.67**±21.81	D	
HLB-2	53.33**±3.67	14.33**±7.34	-80.17**±21.14	-91.33**±20.75	6.83±8.37	84.33**±33.80	D	
HLB-3	63.33**±3.17	10.33**±4.95	-35.16**±18.26	-35.33**±16.12	3.50±6.82	27.68±29.13	D	

PBW502' and 'GW273/HUW468' and 'additive x dominant' and 'dominant x dominant' interactions were more important in crosses 'DBW14/HUW533' and 'GW273/HUW468', respectively. Grain yield/plant in crosses 'DBW14/HUW468' and 'GW273/HUW468' had significance for all gene interactions, whereas 'additive x additive' and 'dominant x dominant' components were significant in 'DL788-2/PBW502', and 'additive x dominant' effects were important in all crosses except 'DBW14/HUW533'. For HLB-1 and HLB-2, 'additive x additive' and 'dominant x dominant' were more important in all crosses except 'DBW14/HUW533', which had a nonsignificant interaction, but 'additive x additive' and 'dominant x dominant' effects were significant for HLB-2 in crosses 'DBW14/HUW533' and 'GW273/HUW468', and an 'additive x dominant' effect was significant in cross 'DL788-2/PBW502'. HLB-3 had significant 'additive x additive' and 'dominant x dominant' gene effects in crosses 'DBW14/HUW468', 'DL788-2/PBW502', and 'GW273/HUW468', but only an 'additive x additive' effect were significant in cross 'PBW443/HUW533', and 'additive x additive' and dominant components were important in the 'DBW14/HUW533' cross.

Dominant (h) and 'dominant x dominant' (l), for their negative and positive gene effects, revealed a preponderance of duplicate types of epistasis, which will hinder improvement of populations where dominant-type gene actions also exist; thus, heterosis can not be exploited in such a situation. The complementary type of epistasis, which is more favorable for genotype improvement, was present in cross I for days-to-maturity, effective tillers/plant, and seed/plant; in cross II for spikelets/spike; in cross III for grains/spike, seed/plant, and HLB-3; and in cross V only for seed/plant. Cross IV had duplicate-type gene interactions for all the characters (Yadav et al. 1997). The results suggest that the nature and magnitude of gene effects vary within the different crosses for different characters, necessitating specific breeding strategys need to be adopted for particular crosses to obtain improvement (Kaur et al. 2004). Characters that were predominantly additive gene effects can use simple selection procedures efficiently, however, dominant and epistatic effects for most of the character in some crosses would slow progress. In such a situation, exploiting additive, dominant, and nonadditive gene effects simultaneously would be beneficial.

For characteristics that are controlled by fixable genes, simple selection or any other breeding methodology that can exploit additive effects might be adopted. For characteristics that are controlled by both additive and dominant gene effects, a breeding plan that exploits both gene effects, such as intermating in early segregating generations followed by selection or reciprocal recurrent selection, might be useful for improvment. For characteristics with complementary-type epistasis in crosses, heterosis breeding may be useful. We observed that a generation mean analysis for most of the characteristics conform with those of previous workers (Luthara et al. 1991, 1996; Singh et al. 1998; Ghannadha et al. 1999; Mehla et al. 2000; Satyavart et al. 2000; Shekhawat et al. 2000; Hamada 2003; Sharma et al. 2001, 2002, 2003, 2004).

References.

- Amawate JS and Behi PN. 1995. Genetical analysis of some quantitative components of yield in bread wheat. *Ind J Genet* 55:120-125.
- Cavalli LL. 1952. An analysis of linkage in quantitative inheritance (Reeva ECR and Washington CH, Eds). HMSO, London, pp. 135-144.
- Dhillon OP, Yunus M, and Waldia RS. 2002. Inheritance of yield and quality components in durum wheat (*Triticum durum* desf.). *Ind J Genet* 62(2):155-156.
- Gamble EE. 1962. Gene effect in corn (*Zea mays* L.). Separation and relative importance of gene effects for yield. *Can J Pl Sci* 42:339-348.
- Ghannadha MR. 1999. Gene action for resistance of wheat (adult stage) to yellow (stripe) rust. *Iran J Agric Sci* 30(2):397-408.
- Hayman BI. 1958. The separation of epistatic from additive and dominance variation in generation mean. *Heredity* 12:371-390.
- Hamada AA. 2003. Gene effect for some agronomic traits in three bread wheat cross. *Ann Agric Scicairo* 48(1):131-146.
- Jinkes JL and Jones RM. 1958. Estimation of the components of heterosis. *Genetics* 43:223-234.
- Luthra OP, Chawla V, Sharma SK, and Tripathi ID. 1996. Genetic studies on slow leaf rusting characters in wheat. *Ann Biol Ludhiana* 12(2):229-231.
- Luthra OP, Chawla V, Maherchandani N, and Yadav B. 1991. Gene effect for parmeters of leaf rusting in wheat. *J Genet Pl Breed* 45(3):155-160.
- Mather K. 1949. Biometrical genetics. Methuen and Co. Ltd., London, UK.
- Muhammad I, Kurshid A, and Choudhary MA. 1991. Genetic analysis of plant height and the above flag leaf node in bread wheat. *Sarhad J Agric* 7:131-134.
- Mostafavi K, Hosseinzadeh AH, and Khaneghah HZ. 2005. Genetic analysis of yield and correlated traits in bread wheat (*Triticum aestivum*). *Iran J Agric Sci* 36(1):187-197.

- Mehla BS, Sharma SC, and Hooda JS. 2000. Gene action for certain quantitative traits in wheat. *Ann Biol Ludhiana* 16(1):95-100.
- Kaur N and Singh P. 2004. Gene effect for grain yield and related attributes in triticum durum. *Ind J Genet* 64(2):137-138.
- Paroda RS and Joshi AB. 1970. Genetic architecture of yield and components of yield in wheat. *Ind J Genet* 30:298-314.
- Singh RP and Singh S. 1992. Estimation of genetic parameters through generation mean analysis in bread wheat. *Ind J Genet* 52:369-375.
- Singh G, Nanda GS, and Sohu VS. 1998. Gene effects for grains per spike, grain weight and grains per spikelet in a set of nineteen crosses of bread wheat. *Ind J Genet* 58:83-89.
- Satyavart, Yadava RK, Raj L, Singh M, and Rana OPS. 2000. Genetics of leaf characters in bread wheat. *Environ Ecol* 18(2):509-511.
- Sharma SN, Sain RS, and Sharma RK. 2003. Genetics of spike length in durum wheat. *Euphytica* 130(2):155-161.
- Sharma SN and Sain RS. 2004. Inheritance of days to heading days to maturity plant height and grain yield in an inter-varietal cross of durum wheat. *SABRAO J Breed Genet* 36(2): 73-82.
- Shekhawat US, Prakash V, and Bhardwaj RP. 2006. Inheritance of grain yield and tillers per plant in wheat (*Triticum aestivum* L.). *Ind J Genet* 66(1):16-18.
- Shekhawat US, Bhardwaj RP, and Prakash V. 2000. Gene action for yield and its components in wheat (*Triticum aestivum* L.). *Ind J Agric Res* 34(3):176-178.
- Simon MR. 1994. Gene action and heritability for photosynthetic activity in two wheat crosses. *Euphytica* 76(3):235-238.
- Singh G, Nanda GS, and Gill KS. 1984. Inheritance of yield and its components in five crosses of spring wheat. *Ind J Agric Sci* 54(11):943-949.
- Sharma SN, Sain RS, and Sharma RK. 2001. Genetics of days to heading maturity and plant height in *Triticum turgidum* var durum over environments. *Crop Imp* 28(2):254-259.
- Sharma SN and Sain RS. 2002. Inheritance of tillers-per-plant in durum wheat (*Triticum durum* Desf). *Ind J Genet Pl Breed* 62(2):101-103.
- Sharma SN, Sain RS, and Sharma RK. 2003. Genetics of spike length in durum wheat. *Euphytica* 130(2):155-161.
- Vimal SC and Vishwakarma SR. 1999. Gene effect controlling yield components in barley (*H. vulgare* L.). *Ind J Genet* 18:21-25
- Yadav B, Yunus S, and Madan S. 1997. Genetic architecture of yield, yield components and quality traits. *Ind J Agric Res* 31:28-32.

G.B. PANT UNIVERSITY OF AGRICULTURE AND TECHNOLOGY
Pantnagar, Uttarakhand, 263 145, India.

Detection of heat shock protein in bread wheat through ELISA.

P.K. Bhowmick, J.P. Jaiswal, and D.S. Gupta (Genetics & Plant Breeding, GBPUAT, Pantnagar), and Anil Grover (University of Delhi, South Campus, New Delhi).

Introduction. High temperature stress is an important abiotic factor that reduces drastically wheat yields in the arid and semi-arid tropics. Howard (1924) reported that for every one degree rise of mean temperature over the range of 12.2–27.53°C, the crop yield is reduced by 4%. To overcome the limits created by higher-temperature stress, a major impetus is on the use of suitable screening techniques to identify heat-tolerant genotypes. Under natural conditions, abiotic stress is usually encountered gradually. Plants, therefore, are exposed to a sublethal stress before being subjected to severe stress. Several studies have shown that plants develop the ability to withstand lethal temperatures upon exposure to sublethal temperatures (known as induction stress). This phenomenon has been termed ‘acquired thermo-tolerance’ (Hahn and Li 1990). During the induction stress, many stress-inducible genes are triggered, which alters several physiological and biochemical processes relevant for stress tolerance. Heat shock proteins (HSP) have been known to play a role in cell protection, survival, and recovery in several species (Vierling 1991; Nguyen et al. 1992). Mild heat treatment induces a so-called heat shock response leading to the immediate induction of a set of new proteins or the over-expression of already existing HSPs that persist over time at high temperature. The 90-kDa HSPs are the second most predominantly